ION PROPULSION MODULE (IPM) TECHNOLOGY READINESS ASSESSMENT – 1985 HALLEY'S COMET RENDEZVOUS MISSION

PRESENTATION TO
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NASA OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY
JPL, 15 JULY 1977

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PRESENTATION OVERVIEW

- ASSESSMENT OBJECTIVE
- APPROACH
- PRODUCTS
- RESULTS
- CONCLUSIONS AND RECOMMENDATIONS

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ASSESSMENT OBJECTIVE

- PROVIDE INFORMATION USEFUL TO NASA IN ASSESSING THE RISK OF UTILIZING ION PROPULSION TO PERFORM A RENDEZVOUS MISSION WITH HALLEY'S COMET IN 1985
- PROVIDE FOR NASA CONSIDERATION RECOMMENDATIONS FOR REDUCING IDENTIFIED RISKS TO THE LOWEST POSSIBLE LEVEL AT PROJECT START IN OCTOBER 1978

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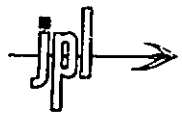

ASSESSMENT APPROACH

- APPROACH BASED ON METHODOLOGY DEVELOPED UNDER NASA/OAST/RX SPONSORSHIP
  - METHODOLOGY APPLIED IN FY 75/76 TO ASSESS THE RISK OF PERFORMING A MARINER JUPITER ORBITER 1985 MISSION
  - METHODOLOGY CURRENTLY BEING APPLIED TO THE VENUS ORBITER IMAGING RADAR AND SEASAT FOLLOW-ON MISSIONS
- ASSESSMENT PERFORMED IN PARALLEL WITH, BUT INDEPENDENT FROM, THE MAINSTREAM ION PROPULSION AUGUST PROJECT EFFORT

ASSESSMENT PRODUCTS

- PRODUCT 1: SUBSYSTEM COMPONENT/ELEMENT LIST
- PRODUCT 2: COMPONENT DESCRIPTIONS
- PRODUCT 3: COMPONENT STATES OF DEVELOPMENT
- PRODUCT 4: COMPONENT COMMITMENT CONDITION ASSESSMENT
- PRODUCT 5: COMPONENT RISK ASSESSMENT
- PRODUCT 6: COMPARISON OF SUBSYSTEM MATURITY AT PROJECT START - IPM VS. PREVIOUS MARINER SPACECRAFT

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ASSESSMENT PRODUCTS (contd)

- PRODUCT 1: SUBSYSTEM COMPONENT/ELEMENT LIST
  - IDENTIFIES THE KEY ELEMENTS COMPRISING THE IPM UPON WHICH THE ASSESSMENT HAS FOCUSED

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ASSESSMENT PRODUCTS (contd)

- PRODUCT 2: COMPONENT DESCRIPTIONS
  - —PROVIDES A DESCRIPTION OF EACH IPM COMPONENT IDENTIFYING ITS
    - FUNCTION
    - GENERAL PHYSICAL CHARACTERISTICS
    - REQUIRED PERFORMANCE TO SUPPORT THE HALLEY MISSION
    - EXPECTED NOMINAL PERFORMANCE
  - —PROVIDES THE BASELINE AGAINST WHICH THE READINESS OF EACH COMPONENT IS EVALUATED

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ASSESSMENT PRODUCTS (contd)

- PRODUCT 3: COMPONENT STATES OF DEVELOPMENT
  - IDENTIFIES, BASED ON THE HARDWARE/SOFTWARE STATE-OF-DEVELOPMENT SCALE SHOWN IN THE NEXT VIEWGRAPH
    - CURRENT STATE OF DEVELOPMENT OF EACH SUBSYSTEM COMPONENT
    - ESTIMATED STATE-OF-DEVELOPMENT, BASED ON CURRENT/PROPOSED DEVELOPMENT PROGRAMS, OF EACH COMPONENT AT PROJECT START
    - REQUIRED STATE OF DEVELOPMENT FOR LOW RISK AT PROJECT START

ASSESSMENT PRODUCTS (contd)

HARDWARE / SOFTWARE STATE-OF-DEVELOPMENT SCALE

LEVEL	STATE OF DEVELOPMENT	
	HARDWARE*	SOFTWARE
1	BASIC PRINCIPLES OBSERVED AND REPORTED	BASIC THEORY DEVELOPED AND PUBLISHED
2	CONCEPTUAL DESIGN FORMULATED	APPLICABILITY TO SPECIFIC PROBLEMS PROPOSED
3	CONCEPTUAL DESIGN SUBJECTED TO ANALYTICAL AND/OR EXPERIMENTAL TEST	USED TO IDENTIFY PARTS OF EXISTING MISSION DESIGN
4	CRITICAL FUNCTION OR CHARACTERISTIC DEMONSTRATED	FAVORABLE COMPARISON WITH AVAILABLE MISSION RESULTS ATTAINED
5	BREADBOARD/PROTOTYPE SUCCESSFULLY TESTED IN RELEVANT ENVIRONMENT	ANALYSES REQUIRED FOR REFERENCE FUTURE MISSION PERFORMED
6	ENGINEERING MODEL SUCCESSFULLY TESTED IN RELEVANT ENVIRONMENT	DEMONSTRATION THAT ALL FUNCTIONS REQUIRED FOR REFERENCE FUTURE MISSION CAN BE PERFORMED TO THE REQUIRED ACCURACY
7	ENGINEERING MODEL SUCCESSFULLY FLIGHT TESTED OR FLOWN IN THE SPACE ENVIRONMENT	SOFTWARE USED IN SUPPORT OF AT LEAST ONE PREVIOUS MISSION

*ABSTRACTED FROM GD CONVAIR RPT. NO. CASD-NA5-75-016, "FUTURE PAYLOAD TECHNOLOGY REQUIREMENTS STUDY," JUNE 1975.

ASSESSMENT PRODUCTS (contd)

- PRODUCT 4: COMPONENT COMMITMENT CONDITION ASSESSMENT
  - PROVIDES AN ASSESSMENT OF WHETHER OR NOT EACH COMPONENT MEETS EACH OF SEVEN CONDITIONS, SHOWN IN THE NEXT VIEWGRAPH, WHICH ARE CONSIDERED ESSENTIAL TO INSURE THAT A PROJECT EMPLOYING THE COMPONENT INCURS LOW RISK

ASSESSMENT PRODUCTS (contd)

CRITERIA FOR COMPONENT COMMITMENT TO A PROJECT

COMMITMENT CONDITION	DEFINITION
1.	THE COMPONENT STATE OF DEVELOPMENT MUST CORRESPOND TO A LEVEL OF 5 ON THE APPROPRIATE HARDWARE OR SOFTWARE STATE-OF-DEVELOPMENT SCALE SHOWN PREVIOUSLY
2.	THE COMPONENT MUST NOT PLACE REQUIREMENTS ON OTHER SUBSYSTEMS WHICH REQUIRE THEIR ADVANCEMENT BEYOND THE STATE-OF-THE-ART
3.	COMPONENT PIECE PARTS (OR THEIR EQUIVALENTS) MUST BE AVAILABLE (AND REMAIN SO) AND MUST MEET PROJECT QUALITY REQUIREMENTS
4.	THERE MUST BE NO UNSOLVABLE PROBLEMS TO THE COMPONENT SURVIVING AND FUNCTIONING IN THE EXPECTED ENVIRONMENTS
5.	COMPONENT MASS, POWER, AND VOLUME ESTIMATES MUST BE COMPATIBLE WITH SYSTEM CAPABILITIES
6.	COMPONENT DEVELOPMENT COSTS, REQUIRED MANPOWER, AND DEVELOPMENT SCHEDULE MUST BE CONSISTENT WITH THE PROJECT PLAN AND ANTICIPATED RESOURCES
7.	COMPONENT MANUFACTURING REQUIREMENTS MUST NOT EXCEED INDUSTRY CAPABILITY IN QUALITY OR QUANTITY

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ASSESSMENT PRODUCTS (contd)

- PRODUCT 5: COMPONENT RISK ASSESSMENT

  —IDENTIFIES THE RISK, BASED ON THE CRITERIA SHOWN IN THE NEXT VIEWGRAPH, THAT THE HALLEY PROJECT WOULD INCUR IN THE AREAS OF

  - TECHNOLOGY
  - ENGINEERING
  - PERSONNEL
  - FORESEEABLE PROBLEMS

  FROM COMMITTING EACH COMPONENT TO THE PROJECT

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ASSESSMENT PRODUCTS (contd)

AREA	LEVELS OF RISK		
	LOW	MEDIUM	HIGH
TECHNOLOGY	TECHNOLOGY EXISTS AND HAS BEEN DEMONSTRATED, CORRESPONDING TO A STATE-OF-DEVELOPMENT LEVEL OF 5 OR HIGHER. ALTERNATIVES ARE BEING DEVELOPED ALTHOUGH THEY ARE NOT YET PROVEN. PARALLEL DEVELOPMENTS ARE POSSIBLE.	TECHNOLOGY EXISTS BUT HAS NEVER BEEN DEMONSTRATED, CORRESPONDING TO LEVEL 4. ALTERNATIVES ARE POSSIBLE BUT ARE COSTLY IN TERMS OF PHYSICAL PARAMETERS OR $. RESOURCES AND SCHEDULE ARE MARGINAL FOR PARALLEL DEVELOPMENTS, BUT PARALLEL DEVELOPMENTS ARE STILL POSSIBLE.	TECHNOLOGY DOES NOT EXIST AND MUST BE DEVELOPED, CORRESPONDING TO LEVEL 1. ALTERNATIVES DO NOT EXIST. PARALLEL DEVELOPMENTS ARE NOT POSSIBLE.
ENGINEERING	PROBLEM IS COMMONPLACE AND MAY BE SOLVED BY THE APPLICATION OF ANY ONE OF A NUMBER OF ROUTINE DESIGN APPROACHES.	PROBLEM IS SOMEWHAT NOVEL AND REQUIRES A DESIGN APPROACH SHOWING SOME INGENUITY AND CREATIVITY.	PROBLEM IS NOVEL, ALTHOUGH SOLUTIONS BASED ON EXISTING TECHNOLOGY DO EXIST, AND REQUIRES A DESIGN APPROACH OF CONSIDERABLE INGENUITY AND CREATIVITY.
PERSONNEL	IMPLEMENTING PERSONNEL ARE AVAILABLE WHO HAVE SUCCESSFULLY SUPPORTED OTHER PROJECTS AND WHO ARE CONSIDERED EXPERTS IN THEIR FIELDS. COMMITMENT OF ABOVE PERSONNEL TO PROJECT FOR ITS DURATION WOULD BE FIRM.	HIGH QUALITY PERSONNEL, BUT WITH LIMITED PROJECT EXPERIENCE, ARE AVAILABLE PERSONNEL COMMITMENT TO PROJECT IS CONDITIONAL.	PERSONNEL OF UNKNOWN CAPABILITIES ARE AVAILABLE. PERSONNEL COMMITMENT TO PROJECT IS UNDETERMINED.
FORESEEABLE PROBLEMS	ENOUGH IS KNOWN TO FORESEE ALL MAJOR PROBLEMS. ENOUGH IS KNOWN TO FORESEE MOST MINOR PROBLEMS.	ENOUGH IS KNOWN TO FORESEE MOST MAJOR PROBLEMS. ENOUGH IS KNOWN TO FORESEE SOME MINOR PROBLEMS.	NOT ENOUGH IS KNOWN TO FORESEE MAJOR PROBLEMS. NOT ENOUGH IS KNOWN TO FORESEE MINOR PROBLEMS.

ASSESSMENT PRODUCTS (contd)

- PRODUCT 6: COMPARISON OF SUBSYSTEM MATURITY AT PROJECT START – IPM VS. PREVIOUS MARINER SPACECRAFT

  – PROVIDES A COMPARISON OF THE ESTIMATED DEVELOPMENT STATUS AT PROJECT START OF THE SUBSYSTEMS OF WHICH THE IPM IS COMPRISED WITH THE STATUS OF THE ENGINEERING SUBSYSTEMS AT PROJECT START OF EACH OF SEVEN PREVIOUS MARINER SPACECRAFT

  – PROVIDES INSIGHT INTO THE RELATIVE MATURITY OF THE SUBSYSTEM TECHNOLOGIES UPON WHICH THE HALLEY MISSION WOULD BE BASED AND PREVIOUS MARINER MISSIONS HAVE BEEN BASED

ASSESSMENT RESULTS

SUMMARY OF PRODUCT 3, 4, AND 5 RESULTS

ASSESSMENT PRODUCTS / IPM SUBSYSTEMS (IN ORDER OF INCREASING RISK)	PRODUCT 3- STATES OF DEVELOPMENT		PRODUCT 4 - COMMITMENT CONDITION ASSESSMENT		PRODUCT 5 - RISK ASSESSMENT							
					TECHNOLOGY		ENGINEERING		PERSONNEL		FORESEEABLE PROBLEMS	
	CURRENT	ESTIMATED OCT 78+	CURRENT	ESTIMATED OCT 78	CURRENT	ESTIMATED OCT 78	CURRENT	ESTIMATED OCT 78	CURRENT	ESTIMATED OCT 78	CURRENT	ESTIMATED OCT 78
STRUCTURE	READY*	(SAME AS CURRENT)	ALL CONDITIONS MET	(SAME AS CURRENT)	L**	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)
DATA HANDLING	READY	(SAME AS CURRENT)	ALL CONDITIONS MET	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)
TEMPERATURE CONTROL	READY	(SAME AS CURRENT)	ALL CONDITIONS MET	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)
POWER	READY	(SAME AS CURRENT)	ALL CONDITIONS MET	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)	L	(SAME AS CURRENT)
THRUST	3-1/2	4	2 CONDITIONS (1 AND 2) NOT MET	(SAME AS CUPRENT)	M	(SAME AS CURRENT)	M	L	L	(SAME AS CURRENT)	M	L
SOLAR ARRAY	3	3-1/2	2 CONDITIONS (1 AND 2) NOT MET	1 CONDITION (1) NOT MET	M	(SAME AS CURRENT)	H	M	L	(SAME AS CURRENT)	M	(SAME AS CURRENT)

KEY:

+ ASSUMING PRE-PROJECT AST TASKS IDENTIFIED IN THE ION DRIVE PROJECT IMPLEMENTATION PLAN AND RECOMMENDATIONS PRESENTED IN THIS ASSESSMENT ARE IMPLEMENTED.

* STATE-OF-DEVELOPMENT LEVEL 5 OR HIGHER

** L = LOW RISK
M = MEDIUM RISK
H = HIGH RISK

ASSESSMENT RESULTS (contd)
SUMMARY OF PRODUCT 6 RESULTS

SPACECRAFT / SUBSYSTEMS	MARINER 4 (MARS FLYBY, 64)	MARINER 5 (VENUS FLYBY, 67)	MARINER 6/7 (MARS FLYBY, 69)	MARINER 9 (MARS ORBITER, 71)	MARINER 10 (VENUS/MERCURY FLYBY, 73)	VIKING (MARS ORBITER ONLY, 75)	VOYAGER (JUPITER/SATURN FLYBY, 77)	HALLEY COMET RENDEZVOUS (ION PROPULSION MODULE ONLY, 82)
RADIO FREQUENCY	4-1/2 *	READY	4	READY	READY	READY	2-1/2	N.A.
FLIGHT TELEMETRY	READY	READY	READY	READY	SEE FLIGHT DATA	SEE FLIGHT DATA	SEE FLIGHT DATA	N.A.
DATA STORAGE	4-1/2	READY	4-1/2	4-1/2	READY	READY	READY	N.A.
ATTITUDE CONTROL	4-1/2	READY	READY	READY	READY	READY	4-1/2	N.A.
AUTOPILOT	READY	READY	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
COMPUTER COMMAND	READY	READY	READY	READY	READY	READY	READY	N.A.
POWER	4-1/2	READY	READY	READY	READY	READY	READY	READY
TEMPERATURE CONTROL	3-1/2	READY	READY	READY	4-1/2	READY	READY	READY
STRUCTURE	4-1/2	READY	READY	READY	READY	4-1/2	READY	READY
PYROTECHNICS	4-1/2	READY	READY	READY	READY	READY	READY	N.A.
CABLING	READY	READY	READY	READY	READY	READY	READY	N.A.
MECHANICAL DEVICES	4-1/2	READY	READY	READY	READY	READY	4-1/2	N.A.
ELECTRONIC PACKAGING	READY	READY	READY	READY	READY	N.A.	N.A.	N.A.
PROPULSION/ THRUST	READY	READY	READY	READY	READY	READY	READY	4
FLIGHT COMMAND	READY	READY	READY	READY	SEE MODULATION-DEMODULATION	SEE MODULATION-DEMODULATION	SEE MODULATION-DEMODULATION	N.A.
DATA AUTOMATION	4	4-1/2	READY	READY	SEE FLIGHT DATA	SEE FLIGHT DATA	SEE FLIGHT DATA	N.A.
SCAN CONTROL	N.A.	N.A.	4-1/2	READY	SEE ARTICULATION AND CONTROL	SEE ARTICULATION AND CONTROL	SEE ARTICULATION AND CONTROL	N.A.
FLIGHT DATA	N.A.	N.A.	N.A.	N.A.	READY	READY	4-1/2	N.A.
MODULATION - DEMODULATION	N.A.	N.A.	N.A.	N.A.	READY	READY	READY	N.A.
ARTICULATION AND CONTROL	N.A.	N.A.	N.A.	N.A.	READY	READY	READY	N.A.
RELAY RADIO	N.A.	N.A.	N.A.	N.A.	N.A.	READY	N.A.	N.A.
SOLAR ARRAY	READY	READY	READY	READY	READY	READY	N.A.	3-1/2
DATA HANDLING	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	READY

KEY: *STATE-OF-DEVELOPMENT LEVEL AT PROJECT START
N.A. NOT APPLICABLE

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ASSESSMENT RESULTS (contd)
OBSERVATIONS ON PRODUCT 6 RESULTS

- MARINER MISSIONS FLOWN SINCE 1964 HAVE NOT BEEN FORCING FUNCTIONS FOR NEW TECHNOLOGY DEVELOPMENT. THEY MAY BE CHARACTERIZED AS LOW RISK, BASED ON TECHNOLOGIES MATURE AT PROJECT START
  - RECENT MISSIONS HAVE NOT DEMANDED TECHNOLOGY DEVELOPMENT

- THE ION DRIVE HALLEY MISSION WOULD DEPART FROM POST-1964 MARINER MISSIONS IN SERVING AS A FORCING FUNCTION FOR NEW TECHNOLOGY DEVELOPMENT IN TWO AREAS: PROPULSION AND SOLAR ARRAY
  - PREVIOUS MARINER MISSIONS HAVE NOT DEMANDED TECHNOLOGY DEVELOPMENT IN THESE AREAS

- SPACECRAFT SUBSYSTEMS RECOGNIZED AS NOT MATURE AT THE START OF A PROJECT HAVE GENERALLY DEMANDED SPECIAL ATTENTION THROUGHOUT THE PROJECT

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ASSESSMENT CONCLUSIONS AND RECOMMENDATIONS

- SYSTEMS-LEVEL CONCLUSIONS
  - MISSION PERFORMANCE MARGIN IS MARGINAL. CURRENT CONTINGENCY 6.7%
  - OPTIONS EXIST FOR IMPROVING PERFORMANCE MARGIN BY SEVERAL 10'S OF Kg'S. GREATER MARGIN INCREASES REQUIRE DEPARTURE FROM BASELINE DESIGN
    - INCREASE OF BEGINNING-OF-LIFE ARRAY POWER TO THE MAXIMUM POSSIBLE TO THE POWER PROCESSOR (~9-10 KW) COULD YIELD 200 Kg (~7 Kg/KW) INCREASED PERFORMANCE MARGIN. REQUIRES 50% INCREASE IN NUMBER OF CELLS, ATTENDANT COST INCREASE, UNCOMFORTABLE DEMANDS ON POWER PROCESSOR

- <u>RECOMMENDATION:</u>
  - ADD EXPERIMENTAL ARRAY DEGRADATION TESTS (5350 HOURS, REAL MISSION EQUIVALENT @ 1 SUN) NOT CURRENTLY SHOWN IN PROJECT PLAN TO CONFIRM 12% ARRAY DEGRADATION MODEL, CURRENT PERFORMANCE MARGIN
  - CONTINUE INVESTIGATION OF ALTERNATE DESIGNS WHICH MIGHT YIELD PERFORMANCE MARGIN INCREASES

ASSESSMENT RESULTS AND CONCLUSIONS (contd)

- SUBSYSTEM-LEVEL CONCLUSIONS
  - STRUCTURE, DATA HANDLING, TEMPERATURE CONTROL, AND POWER SUBSYSTEMS RISK FORECAST AT PROJECT START IS LOW

RECOMMENDATION:

- PROCEED AS SHOWN IN PROJECT PLAN

- THRUST SUBSYSTEM RISK FORECAST AT PROJECT START IS MEDIUM
  - RISK RATING DRIVEN BY UNDEMONSTRATED THRUSTER LIFETIME REQUIREMENT OF 12-14,000 HOURS (6000 HOURS WILL BE DEMONSTRATED)
  - LeRC, HUGHES RESEARCH LABS, AND JPL CONTROL AND ENERGY CONVERSION DIVISION ALL CONFIDENT OF SUCCESS
  - CONFIDENCE APPEARS JUSTIFIED. POSITIVE RESULTS FROM FY 78 EFFORT WILL REDUCE - BUT STILL NOT ENTIRELY ELIMINATE - IDENTIFIED RISKS

RECOMMENDATION:

- CONDUCT LIFE TESTS AS SHOWN IN PROJECT PLAN

ASSESSMENT RESULTS AND CONCLUSIONS (contd)

- SUBSYSTEM-LEVEL CONCLUSIONS (CONTD)
  - SOLAR ARRAY SUBSYSTEM RISK FORECAST AT PROJECT START IS MEDIUM
    - RISK FORECAST DRIVEN BY UNCERTAINTY OVER CELL PERFORMANCE (CELL DEGRADATION) AND CELL MANUFACTURABILITY TO SPACECRAFT STANDARDS
    - GENERAL ELECTRIC AND JPL CONFIDENT OF SUCCESS
    - POSITIVE RESULTS FROM FY 78 EFFORT WILL REDUCE - BUT NOT ENTIRELY ELIMINATE - IDENTIFIED RISKS

RECOMMENDATION:

- CONDUCT CELL PRODUCTION DEMONSTRATION AS SHOWN IN PROJECT PLAN
- MEASURE SUCCESS AGAINST CRITERIA WHICH DEFINE THE PERFORMANCE CHARACTERISTICS AND QUALITY CONTROL STANDARDS ACCEPTABLE CELLS MUST MEET

ASSESSMENT CONCLUSIONS AND RECOMMENDATIONS (contd)

- GENERAL CONCLUSIONS
  - — COMMITMENT TO ION DRIVE HALLEY MISSION INVOLVES RISK
  - —UNCERTAINTIES REQUIRE AMBITIOUS, AGGRESSIVE PRE-PROJECT AST PROGRAM IN FY 78 TO REDUCE UNCERTAINTY, IMPROVE CONFIDENCE
  - —GO-AHEAD DECISION AT THIS POINT SHOULD NOT BE CONSIDERED A COMMITMENT TO THE MISSION. DECISION MUST BE BASED ON RESULTS OF FY 78 EFFORT.